Proceedings of the Interdisciplinary STEM Teaching and Learning Conference

Volume 2 Article 5

2018

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A mixed methods, action research case study was conducted to investigate the effects of incorporating LEGO robotics into a seventh-grade mathematics curriculum focused on the development of proportional reasoning through the lens of Social Constructivist Theory. This study applied students' prior knowledge of the distance, rate, and time formula as they used LEGO EV3 robots to calculate the rate of a robot. The information gained was applied to different iterations, and structures, of the formula to support the development of proportional reasoning skills. The purposefully designed lessons were integral to the development of the students' understanding of the proportionality existing among the variables. The quantitative analysis reflects the acquisition of understanding of proportional relationships with the greatest increase being from low-performing students. The qualitative analysis provides an in-depth look at how students used their understanding of the distance, rate, and time relationship to develop proportional reasoning skills. Overall, the inclusion of robotics was productive for learning; however, future studies should be completed, on larger student populations, as a means to validate the quantitative findings and continue to improve the curriculum.

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Recommended Citation

Casler-Failing, Shelli L. (2018) "The Effects of Integrating LEGO Robotics Into a Mathematics Curriculum to Promote the Development of Proportional Reasoning," *Proceedings of the Interdisciplinary STEM Teaching and Learning Conference:* Vol. 2 , Article 5.

Available at: https://digitalcommons.georgiasouthern.edu/stem_proceedings/vol2/iss1/5

Introduction

As a middle school mathematics teacher, I was always looking for ways to engage my students in authentic learning tasks that were engaging, hands-on, and, most importantly, fun for the students. However, I did not want the fun and engaging part to replace the learning and understanding aspects of the curriculum. Furthermore, knowing technological advances have increased the demand on educational programs to create students who are thinkers and doers; I wanted my students to be able to apply their knowledge while working in collaborative environments. I knew the "drill and kill" solution to learning mathematics was no longer a viable solution to advancing through mathematics education – students should be able to develop a solution, and apply that solution, when given a problem. With this in mind, mathematics teachers, myself included, need to create avenues to educate students to produce the type of person that is capable of succeeding in today's technological world.

According to the *Partnership for 21st Century Skills* students require hands-on, engaging activities that promote intrinsic motivation to learn and acquire the skills so sought after in this 21st Century (2014). Carbonaro, Rex, and Chambers (2004) believe education needs to shift; instead of learning from technology (i.e., computer programs) students should learn with technology (i.e., robotics). Therefore, future research needs to be gathered with this thought in mind, which brings us to the research being reported in this paper. I sought to engage my students in authentic tasks by the integration of technology, namely LEGO robotics, into the educational environment to promote and enhance learning. When robotics are appropriately integrated into the mathematics classroom through specific tasks and challenges, students can "develop more sophisticated solutions and understandings of those solutions" (Silk, Higashi, Shoop, & Schunn, 2010, p. 21). If students are given the opportunity to learn mathematics through the use of LEGO robotics they would be provided with hands-on, engaging activities that promote learning.

A specific area of interest, that I felt could be supported by LEGO robotics technology, is how students develop proportional reasoning skills. Proportional reasoning has been a focus of research for over fifty years and has once again come to the forefront with the onset of the Common Core State Standards in Mathematics (CCSSM). Although CCSSM has recently become a topic of concern for educators, proportional reasoning has been a topic of much importance for mathematics educators since the 1970's due to its influence on student success in higher-level mathematics (Jitendra, Star, Dupuis, & Rodriguez, 2013).

Langrall and Swafford (2000) claim a student's ability to reason proportionally is imperative to aid their mathematical understanding at higher levels of mathematics and therefore it must be developed and strengthened during the middle school years. For the purposes of this research, I defined proportional reasoning as one's ability to determine the multiplicative relationship between two quantities and to apply that knowledge to predict how the quantities will be affected when one of the quantities is changed.

Previous research studies incorporating LEGO robotics have reported positive results. Martinez Ortiz (2015) investigated the effects of robotics on students' proportional reasoning skills through a one-week, extra-curricular intervention. The findings of his research showed that although there was not a statistically significant difference in student achievement at the end of the intervention period for either the

DOI: 10.20429/stem.2018.020105

Intra-Prop or Extra-Prop questions, there did exist a moderate difference in student understanding on the final assessment given ten weeks after the completion of the intervention for the experimental group; a significant difference was found for the both the end of intervention and ten-week assessment for the Engin-Prop questions with the experimental group (Martinez Ortiz, 2015).

Ardito, Mosley, and Scollins (2014) integrated robotics into a sixth-grade mathematics class and found the highest level of success achieved by the students was in the areas most reflective of problem solving and critical thinking skills – Algebra; Measurement; and Statistics and Probability. Williams, Igel, Poveda, Kapila, and Iskander (2012) investigated the effects of integrating robotics into mathematics and science curricula classes and found the students' mathematics understanding improved by 25%, their science understanding improved by 47% and student surveys showed that students preferred the hands-on learning afforded by robotics.

The portion of my research project being reported in this paper investigated how the application of the distance, rate, and time relationship through the use of LEGO Robotics influenced the development of proportional reasoning skills among seventh grade students. More specifically, this portion of the research study sought to explore how students' solution strategies to distance, rate, and time problems supported the growth of developing, and applying, proportional reasoning skills. The research questions guiding this research were:

(1) How does the incorporation of LEGO robotics into a unit on ratios and proportions influence students' proportional reasoning?
(2) In what ways do students reason about distance, rate, and time while using the LEGO robots?

My research study investigated the four main types of proportional reasoning problems: part-part-whole, associated sets, well-known measures, and growth[1]. Part-part-whole problems relate two subsets (e.g., lions or tigers) to one another or one of the subsets to the whole (e.g., number of tigers as compared to the whole population of zoo animals). Associated sets are proportional relationships with quantities that are not regularly associated with one another (e.g., ounces of juice and students). Well-known measures involve quantities that are regularly associated together (e.g., miles per hour is equal to speed). Growth problems deal with the dilation or shrinking of objects (e.g., a photo is enlarged from 3x5 to 4.5x7.5) and are considered to be the most difficult types of problems for students to master (Langrall & Swafford, 2000; Lamon, 1993).

Theoretical Framework

This research was guided by the Social Constructivist Theory as explained through the work of Lev Vygotsky (Moll & Whitmore, 1993; Cobb, Wood, & Yackel, 1993; Hatano, 1993; Vygotsky, 1978; Wertsch, 1985). Vygotsky's (1978) Social Constructivist Theory was based on his belief that learning was a result of social activity which allowed children to construct knowledge and understanding by playing and conversing with other children and adults. This theory was the foundation for the development of the

[1] The results of the growth problems will be presented in a separate paper as they were investigated separate from the distance, rate, and time formula.

curriculum and every investigation and activity was designed to focus on the social aspect of LEGO robotics. I was careful to incorporate discussion and *play* into the curriculum as students used the robots for learning. As the students worked through structured tasks, the LEGO robots required the "children [to] solve practical tasks with the help of their speech, as well as their eyes and hands" (Vygotsky, 1978, p. 26).

As the research was analyzed, another framework, primarily applied to problem-based learning (PBL), evolved. Carbonaro, Rex, & Chambers (2004) found when working in PBL environments that technology integration must involve five stages in order to be effective. The stages are engagement – teams are formed, the challenge explained, and questions are asked; exploration – perform specific tasks to acquire knowledge and skills; investigation – make predictions, plan experiment, and test; creation – design, test and modify as needed; and evaluation – present findings to peers and formal/informal assessment of knowledge gained (Carbonaro, Rex, & Chambers, 2004). As I analyzed the data, these stages were very pronounced and became an important piece of the coding scheme. Since this framework relates closely with Social Constructivist Theory, it was used to analyze the research data.

Methodology

The mixed methods format utilized for this action research allowed me to assess the students' growth of understanding, document student engagement, and allowed for student feedback to become part of the data collection. The participants studied were six (6) students in my seventh-grade mathematics class who attended a small, progressive, independent school. The research was comprised of a pre- and post-test, eight purposefully designed lessons/investigations (see Appendix A to view a lesson), and three activities (given at specific intervals throughout the intervention). [2] The activity completed after investigation 4 is shown in Appendix B.

This research integrated the use of the LEGO Mindstorms EV3 Robots (see Figures 1 and 2) programmed with a basic movement block (see Figure 3) that was relatively easy for students to understand and manipulate. The students were purposefully grouped into heterogeneous pairs to complete the investigations. The data collected consisted of pre- and post-tests, classroom observations, student interviews, field notes, student journals, and student work artifacts. The four investigations addressing the concept of distance, rate, and time were specifically designed for this research and allowed students to change the values of time and speed in the programming block as required in each investigation.

Figure 1. Right Side View of Driving Base

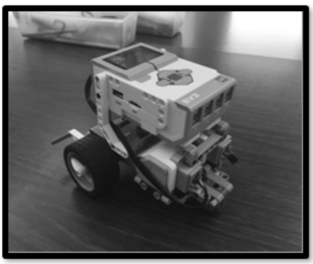

Figure 2. Left Side View of Driving Base

[2] The research reported in this paper only involves the first four lessons/investigations and one activity.

DOI: 10.20429/stem.2018.020105

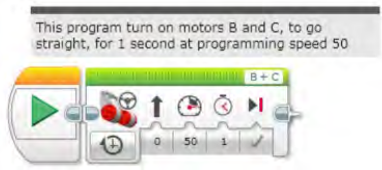

Figure 3. Mindstorms program for Investigations 1-4

Results

The data was analyzed quantitatively and qualitatively. Due to the extremely small sample size, the quantitative data does not provide reliable data from which conclusions can be drawn, but was included as evidence of student learning. The qualitative data was included as a means to look deeper into the students' work to develop an understanding of *how* the students' proportional reasoning skills may have developed.

Quantitative Results

The results shown below (Figure 4) reflect the actual scores received by the students on each of the tests.[3] As shown, the results of the pre-test varied from a low of 0% (Student 5) to a high of 60%. The results of the post-test, as compared to the pre-test provide evidence of growth in the students' proportional reasoning skills with the grades ranging from a low of 57% accuracy to a high of 97% accuracy. The quantitative data represent a percent increase from pre- to post-test varying from 33% to 5700% (further statistical analysis was not completed due to the small sample size). An important aspect to note is that although Student 5 had a post-test grade below passing, it was not due to a lack of proportional reasoning skills, but rather a lack of accurate interpretation on some of the problems. This fact was substantiated during the final interview when problems similar to those interpreted incorrectly on the post-test were completed and explained accurately.

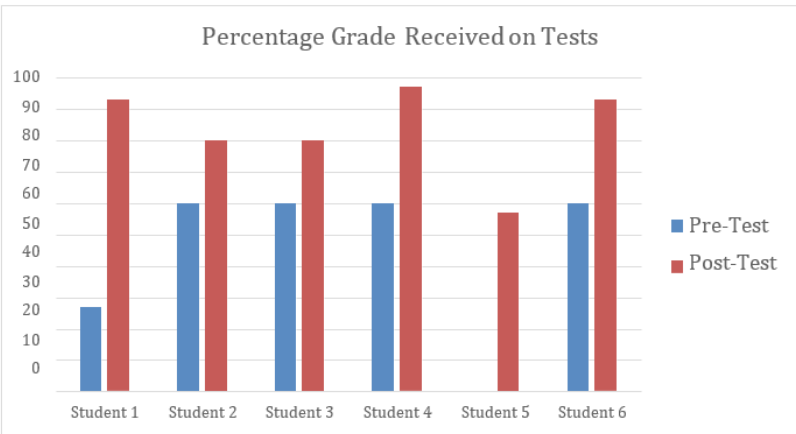

Figure 4. Results of Pre- and Post-Tests[4]

[3] Growth problems, part of the entire research project, have been omitted from the results.
[4] Student names have been omitted to eliminate identifiers.

In addition to the overall test scores, each question on the pre- and post- tests were analyzed according to Langrall and Swafford's Proportional Reasoning Rubric (2000). The rubric allows for classification of students' proportional reasoning among four levels - non-proportional reasoning, informal reasoning about proportional situations, quantitative reasoning, and formal proportional reasoning. At the non-proportional reasoning stage students are likely to make guesses or randomly choose numbers. At the informal reasoning stage students may draw pictures to represent their understanding. Students at the quantitative reasoning stage have begun the transition from additive to relative thinking and begin to understand and use scale factors. At the formal proportional reasoning stage students understand how to set up and solve proportions (Langrall & Swafford, 2000).

The results for each student are shown in Figure 5 below. The figure depicts the development of proportional reasoning skills by each of the six students who participated in the research study. Each of the six students developed and/or improved proportional reasoning skills. Students 1 and 5, who are low-performing students, reflected the most growth in their proportional reasoning skills. The low-performing students demonstrated informal proportional reasoning skills (level 0) on the pre-test, but developed quantitative and formal proportional reasoning (levels 2 and 3), as demonstrated on the post- test.   Students 3 and 6, average-performing students, exhibited growth by improving to consistently reflect quantitative and formal proportional reasoning skills on the post-test. Finally, students 2 and 4, high-performing students, demonstrated improved understanding of proportional reasoning as shown by their growth from the pre-test to the post-test.

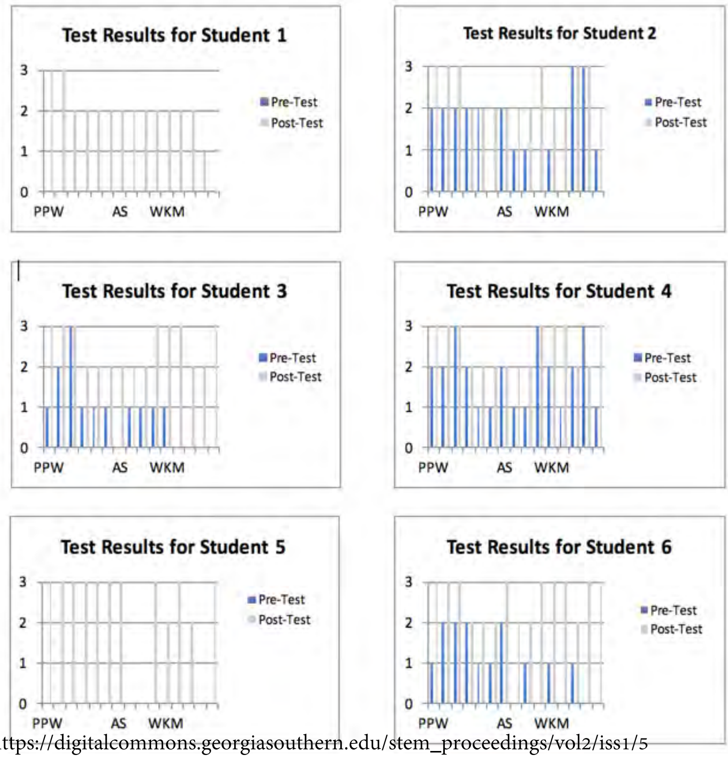

Figure 5. Results of pre- and post-test by question type.[5]

[5] The abbreviations in the table refer to the problem types: part-part-whole (PPW), associated sets (AS), and well-known measures (WKM).

Qualitative Results

I analyzed students' discussions as the students solved problems involving distance, rate, and time, to identify the students' application of the five stages of technology integration (Carbonaro, Rex, & Chambers, 2004) and determine how this integration guided the development of understanding.

Carbonaro, Rex, and Chambers (2004) reported the students appeared to progress through the stages in a linear fashion in the PBL environment, however, in my research the students' movement among the stages was more fluid. Engagement was an overarching stage, present at each of the other levels, and students progressed through the stages *as needed*. For instance, students may have read a question, explored a solution, created a solution, evaluated the findings, and, if wrong investigated why it was wrong, which may have required the creation of a new solution. It was the progression among these stages in which the students' understanding of proportional reasoning was developed, improved, and applied.

Student discussion was an important aspect of each investigation within, and among, each of the groups and was an important factor in how students applied their knowledge about distance, rate, and time to create, and analyze, proportions related to their given tasks; decisions made within all three groups were made by both group members and not by one individual. Students were applying the DRT formula in each of its three forms ($d = rt$, $r = {}^{d}/_{t}$, or $t = {}^{d}/_{r}$), in order to respond to the tasks presented in each investigation. It was through the understanding of these formulas that students were able to make sense of, and create, proportions. For example, when students were working with the same programming speed, say 50, they knew their robot's rate was approximately 24 cm/s (from previous tasks). After determining the time required to travel a specific distance at this rate, they would be able to predict the time needed to travel a different distance by applying the following proportion:

$$\frac{known\ distance}{known\ time} = \frac{new\ distance}{x}$$

The students were able to substitute the known numbers, calculate the predicted time, input the information into the program software, and test their prediction. Once students obtained the results, they were required to justify their answer if they were correct or determine possible causes of error if they were incorrect. It was through these actions, and the conversations occurring as these actions were completed, the students' understanding was developed. It became clear, while analyzing the conversations, this was how the students were developing proportional reasoning skills. An example would be the following conversation when students were attempting to determine the rate at programming speed 25 when they knew the rate at programming speed 50:

Casey: …the speed of 50.
Bailey: That means you do half the rate.
Casey: Half the rate?
Bailey: Or double the rate, I'm not sure.
Casey: No, half the rate because if we double the rate then we're going too fast.

Another consistency among the groups was the ability of the students to *make sense* of the data. For example, Dakota stating, "if it went that far with 5 seconds, maybe we should try some smaller numbers" or Bailey saying, "That doesn't make sense, what did I do wrong?"

The investigation and activities designed for this portion of the research were developed in a manner to support student's development of proportional reasoning skills by applying their knowledge of distance, rate, and time through the tasks presented. The format required the students to work together to predict, program, test, and evaluate their data; each of these tasks required the students to perform an activity (e.g., calculate numbers, measure a distance), thus applying the DRT formula while developing and/or improving proportional reasoning skills.

Discussion

Implications of Research

My research has provided evidence to support the inclusion of robotics as a means to apply student understanding of the distance, rate, and time relationship to improve students' development of proportional reasoning. The inclusion of robotics promoted discussion within, and among, student groups as they worked through the investigations and activities. In this day and age when so much attention is given to purposeful technology integration, units such as the one I developed for this research is beneficial – it provides an example of how technology integration can support the learning of mathematics. This type of technology integration allows students to learn *with* technology rather than *from* technology (Carbonaro, Rex, & Chambers, 2004).

Throughout education students have been developing proportional reasoning skills in mathematics classrooms through many different methods (e.g., lecture or manipulatives) long before the introduction of robotics. The inclusion of robotics to promote the development of proportional reasoning skills may not be a unique method for promoting understanding, but it is a meaningful method.

LEGO Robots allows students to *see* proportionality as they progress through the activities. Students echoed this statement through their responses to the interview question, "How do you feel about using the robots in math class? Do they help you learn better?" Each of the four interviewed students[6] replied with similar responses:

Jordan: "I feel like they can actually really help with the ratios and proportions because the way, or the things that we've been doing so far have helped me better understand, I think, rather than using a book. Cause [sic] with a book sometimes you can't really understand what you're doing, but with the robots you can actually see what's happening and calculate further."

Dakota: "Yeah, because its more hands on than just like, here's a worksheet fill out the answers… cause in life if you have…a math problem integrated in life you're not going to be handed a worksheet. You have to analyze it and then figure out from that. That's sorta [sic] what we're doing with the robots."

[6] The gender-neutral student names are pseudonyms to ensure student anonymity.

DOI: 10.20429/stem.2018.020105

Casey: "I think it's good, like, I think it's fun and you learn things, like, like, uh, rates and times and distances. I like using the robots better than just doing math on paper…it's more fun with the robot…it's, like, more interactive so you're doing something and then you're learning math, not just looking at a workbook, reading the question, and writing whatever's down on it."

Harley: "I like it a lot…. because it's, like, you can see what you're doing. If you program something and you turn on the robot and it goes however long it goes, you can see what you're doing and if it messes up you can always improve instead of, like, writing on a sheet of paper… you messed this up and you have to, like, redo it, but…you can see what you did…"

The LEGO robots bring another dimension to the learning, a sense of play that tends to mask the learning, in my experience. I have witnessed students struggle to arrive at the "correct" answer and give up when working out of a book, with a worksheet, or with manipulatives. However, when students are learning collaboratively with robots they tend to have much more perseverance – they continue to talk through the issues and try different numbers in the program until they arrive at the answer – the robots create a "can-do" environment. My experience as a mathematics teacher has allowed me to witness that low- performing students tend to "give up" more quickly than average- or high- performing students. However, it was the low-performing students that achieved the greatest growth in my research, which, I believe, is due to the positive environment generated through the playfulness of the robots. I argue LEGO robotics provides students the opportunity to develop proportional reasoning skills in a manner more effective than other learning methods due to the playful aspect and positive environment created by the robots.

Limitations of Research

The results of the quantitative data show the students developed proportional reasoning skills, as evident in the change in the levels of proportional reasoning from the pre-test to the post-test and overall improvement in test grades, but since the class consisted of only six students the data is not generalizable to larger populations. The breadth and depth of the qualitative analysis was limited as well. The breadth of the data analysis was limited as with a small class size there is a lack of multiple occurrences of comments and/or actions. The depth is limited because although I was able to find evidence of the benefit of robotics, it is insufficient verification due to having only six students.

Proposed Changes for Future Research

This research provided evidence for the positive effects of incorporating LEGO robotics into a mathematics curriculum focusing on the development of proportional reasoning. However, after conducting the research and analyzing the data, I have found areas I would like to improve to produce stronger, more convincing evidence for the power of robotics inclusion in future studies. In addition to researching a larger sample of students, future studies will include at least one additional investigation to focus more clearly on ratios (separate from proportions), will include different types of daily journal questions (more objective to better assess student understanding), and will investigate, in more depth, the playful nature of the robotics.

Conclusion

The findings show students reason about distance, rate, and time through discussion as they transition through the five stages of technology integration (Carbonaro, Rex, & Chambers, 2004). It is through this process the students develop, improve, and apply proportional reasoning skills. The students reported the benefit of incorporating robotics into the unit as it allowed them to learn in a visual manner and more easily determine accuracy – they could see if they were right or wrong. In addition, the creative and playful aspect of the robotics appeared to create a natural engaging environment for student learning. When students are given the opportunity to learn mathematics through the use of LEGO robotics they are provided with hands-on, engaging activities that assist in, and promote, learning.

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Appendix A

Rates and Proportions - Investigation 2
How much time do I need?

In Investigation #1, "What is my rate?" you determined the rate at which the robot travels at programming speed 50. In this investigation, you will use your knowledge of the robot's rate to determine different times that are needed to travel a specific distance.

This lesson will allow students to continue to develop their ability to reason proportionally. The objective of this lesson is for students to begin to reason proportionally as they predict how the rates of the robots will change from a programming speed of 50 to a programming speed of 25, or 100.

Class Discussion:

1) How can I use a known speed to determine how much time is needed to travel a specific distance?
2) What variables could affect your predictions and results?

Group Work:
For each question below, you will first need to predict the time required, program the time using the software, and test your prediction. If your prediction is inaccurate, you will need to continue to test until you find the correct time.

In Investigation #1 you determined your robot's average rate at programming speed 50.

What was your robot's average rate? ______cm/s

1) How much time is needed for your robot to travel at programming speed 50 for 15 cm?

   Was your prediction correct? If not, what was the time needed?
   Why do you think your calculations were incorrect?
2) How much time is needed for your robot to travel at programming speed 100 for 25 cm?

a. What do you predict the robot's rate will be at programming speed 100? Why?
b. Was your prediction correct? If not, what was the time needed? Why do you think your calculations were incorrect?

3) How much time is needed for your robot to travel at programming speed 25 for 50 cm?
   a. What do you predict the robot's rate will be at programming speed 25? Why?
   b. Was your prediction correct? If not, what was the time needed? Why do you think your calculations were incorrect?
4) Develop your own speed rate and distance, make the prediction and test your results. Make sure to record your speed, distance, time prediction and results.

Appendix B

Rates and Proportions – Check-Up
Activity Sheet #1

I would like you to answer each of the following questions. You may work in your groups to complete these problems. You must show all of your work and answer each question completely. Please add any comments you feel are necessary to explain your thinking.
All of these problems were taken from *Connected Mathematics 2* "Comparing and Scaling: Ratio, Proportion, and Percent." (Lappan, Fey, Fitzgerald, Friel, & Defanis Phillips, Comparing and scaling: Ratio, proportion, and percent, 2006, p. 7)

This activity will be given to students during class upon the completion of the first four investigations. The objective of this activity is to document the students' ability to transfer their new knowledge to problems requiring proportional reasoning skills to determine a solution.

1) Students at Neilson Middle school are asked if they prefer watching television or listening to the radio. Of 150 students, 100 prefer television and 50 prefer radio.
   a. Determine if each statement accurately reports the results of the Neilson Middle School survey by answering true or false. Please justify your answer in detail.
      i. At Neilson Middle School, $^1/3$ of the students prefer radio to television.
      ii. Students prefer television to radio by a ratio of 2 to 1.
      iii. The ratio of students who prefer radio to television is 1 to 2.
      iv. The number of students who prefer television is 50 more than the number of students who prefer radio.
      v. The number of students who prefer television is two times the number who prefer radio.
      vi. 50% of the students prefer radio to television.

DOI: 10.20429/stem.2018.020105